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Assessment of an iconic-geometric nonlinear registration method for deep brain stimulation (DBS) planning

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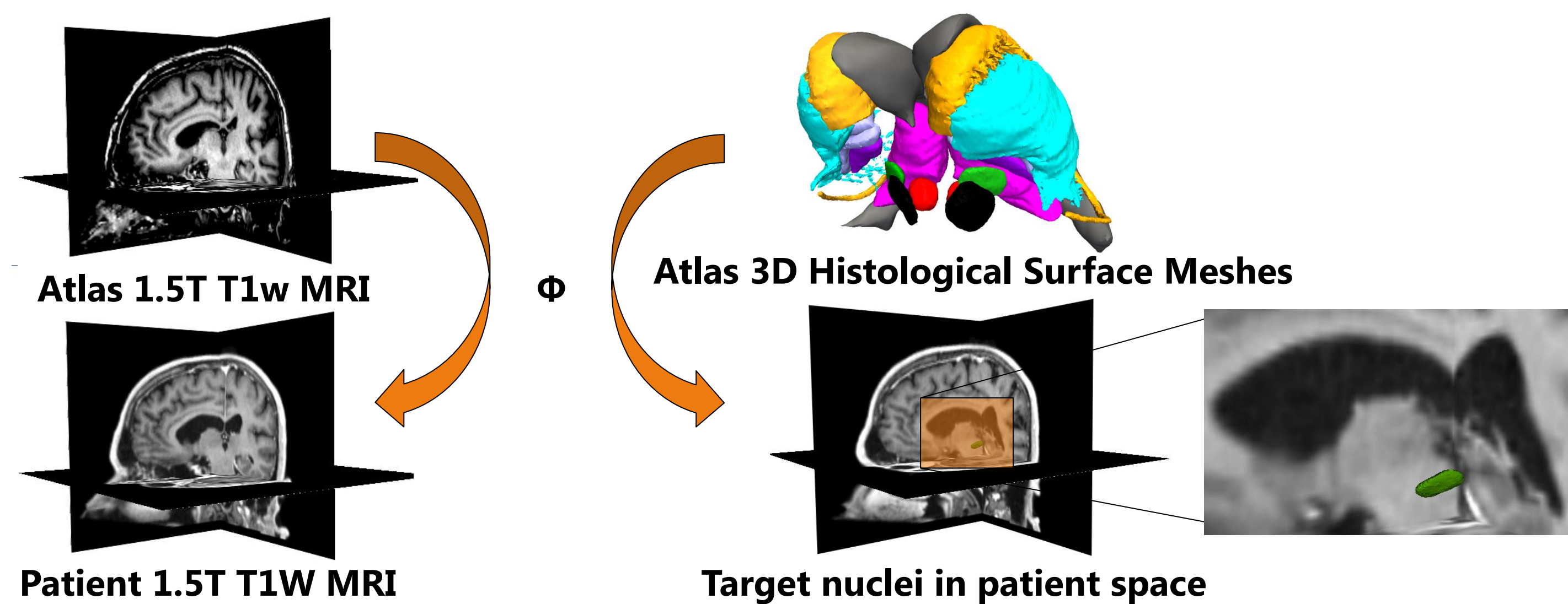
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INTRODUCTION

- **Context:** successful DBS surgical outcome depends on precise electrode implantation. To plan the implantation strategy, pre-operative **targeting** is performed to estimate the location of basal ganglia (BG) stimulation nuclei in the patient's brain.
- **Targeting Strategies:** direct visual inspection of the BG nuclei in MRI is not always possible, requiring the use of indirect methods, such as **atlas-based targeting through image registration**.
- **3D Histological Atlas of the Basal Ganglia [1]:** a 3D model of the human BG, obtained from the co-registration of histological and 1.5T T1-weighted (T1w) MRI data of a healthy elder specimen.
- **Deformation Models:** embed different degrees of freedom and desirable properties in the solution of the atlas-to-patient registration (rigid, affine, nonlinear).

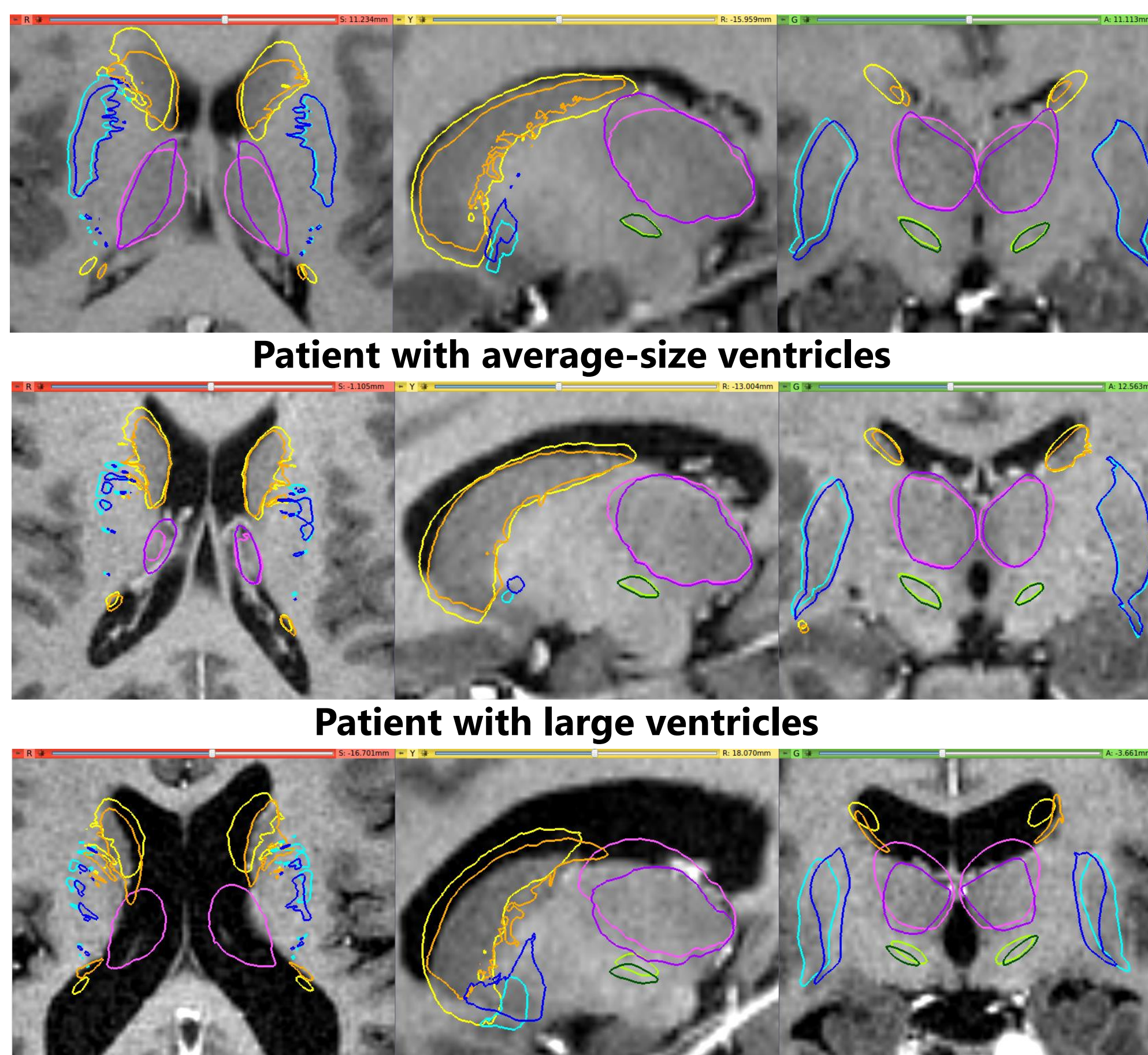


- **Challenges:** deform atlas structures of histological precision based on 1.5T T1w MRI data where certain BG nuclei are invisible; respect anatomical shape properties; cope with anatomical variability among patients.
- **Our Solution:** a **nonlinear diffeomorphic** registration algorithm based **simultaneously** on **intensities** (image data) and **geometric** (shape data) constraints.

REGISTRATION RESULTS

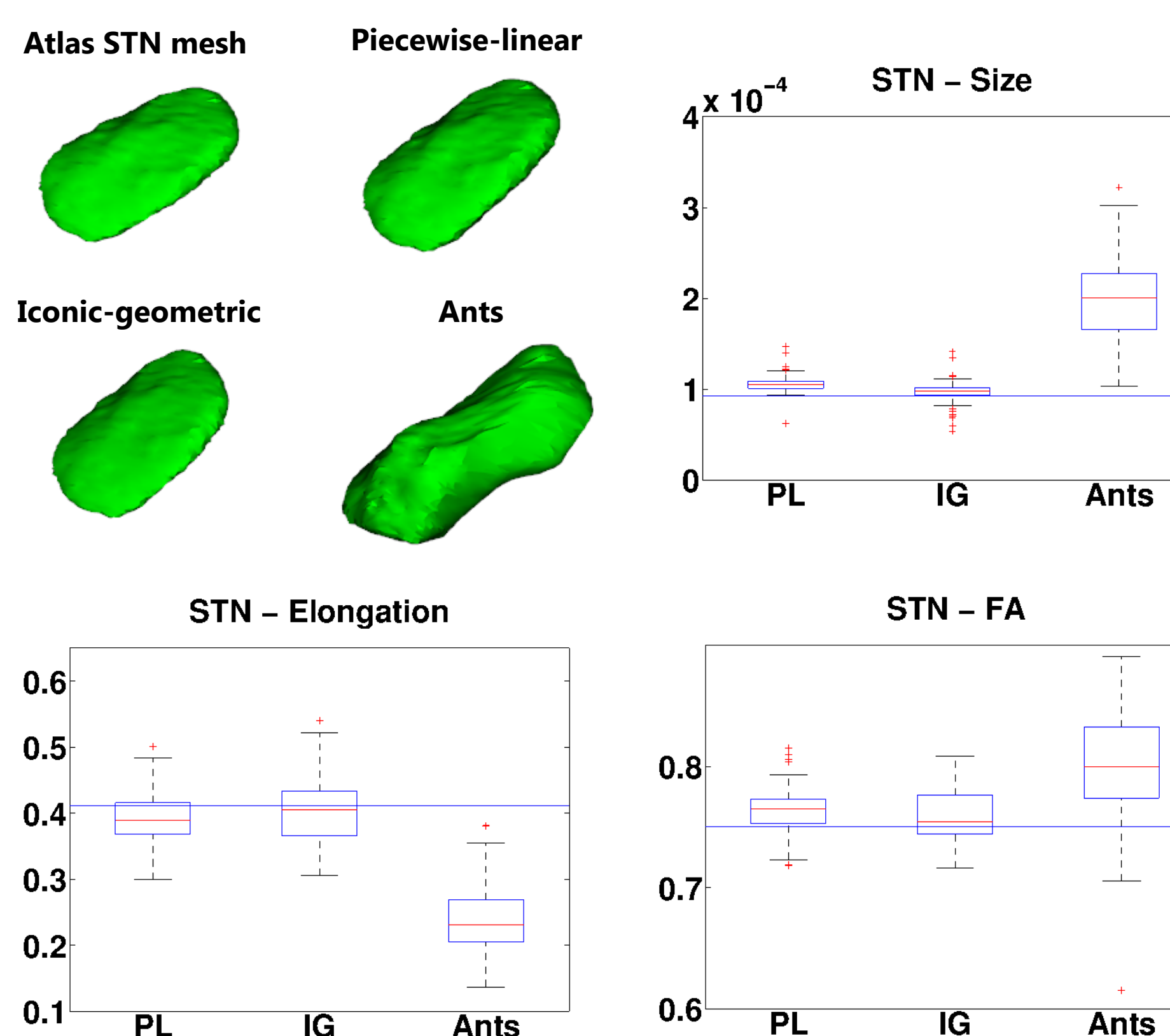
- **Cohort :** 30 Parkinsonian patients undergone bilateral DBS of the subthalamic nucleus (STN).
- **Patient Data:** 1.5T T1w / T2w MRI; patient Freesurfer subcortical meshes; per-operative annotations of microelectrode recording labels (MERL).
- **Evaluated Registration Methods:** piecewise-linear (PL), PL followed by iconic-based nonlinear ANTS (default parameters), PL followed by the iconic-geometric nonlinear method (IG).
- **Iconic-Geometric Registration Data:** 1.5T T1w MRI (atlas/patient); pairs of Freesurfer surface meshes representing the left/right lateral ventricle, caudate nucleus, putamen, and thalamus of the atlas and a patient.

Piecewise-linear (bright colors) and iconic-geometric (dark colors) results

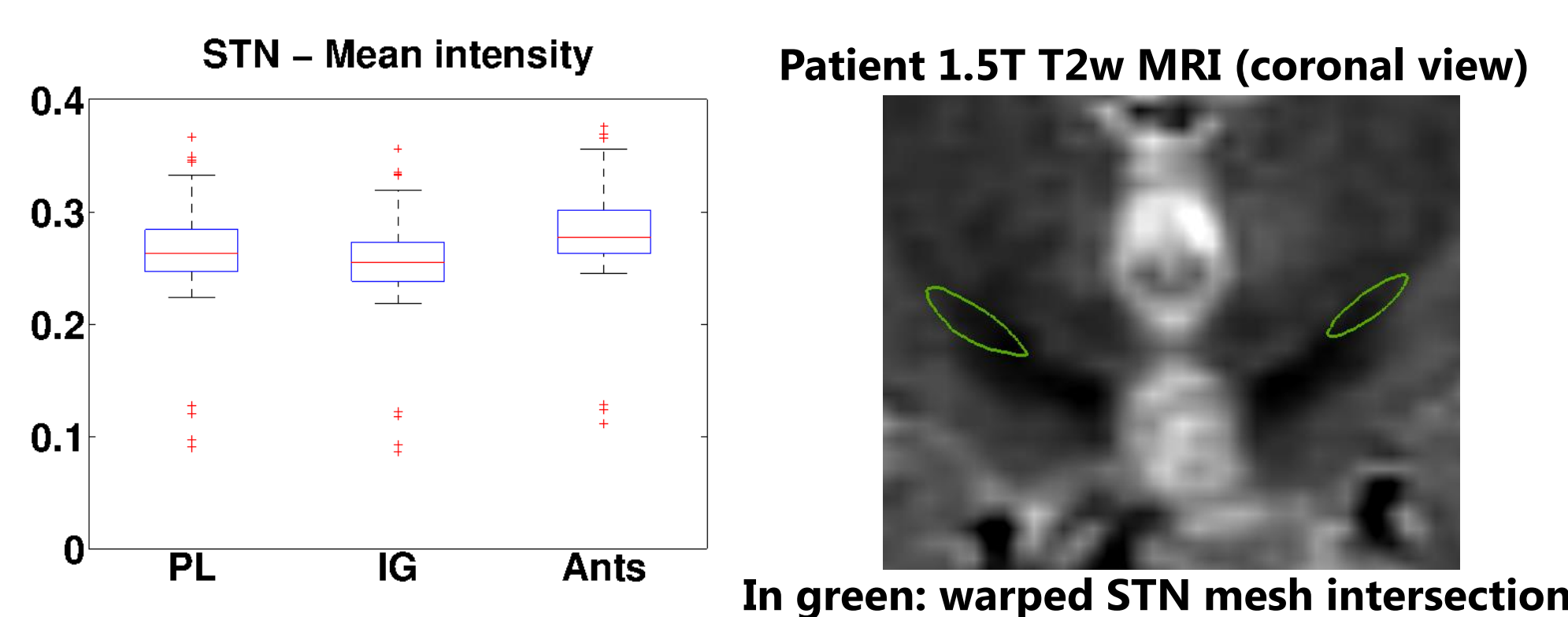


QUANTITATIVE EVALUATION

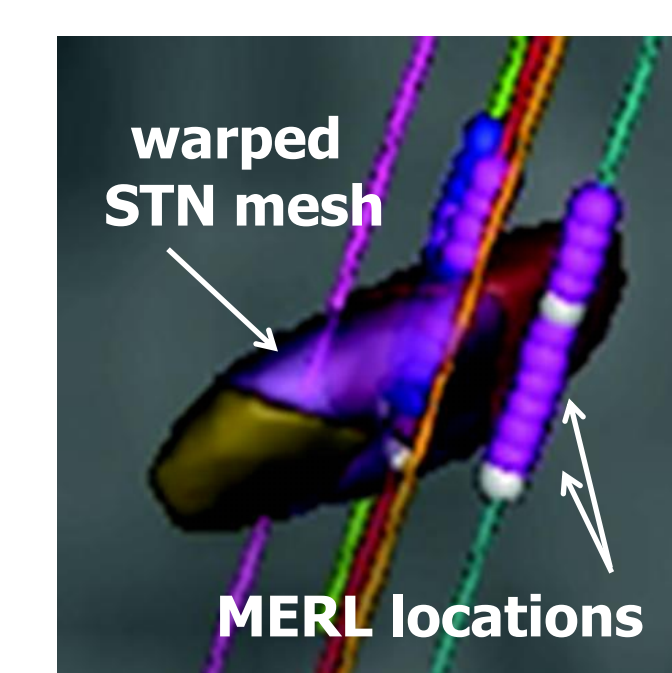
- **Shape measures** (size, elongation, and fractional anisotropy or "sphericity") from warped STN meshes.



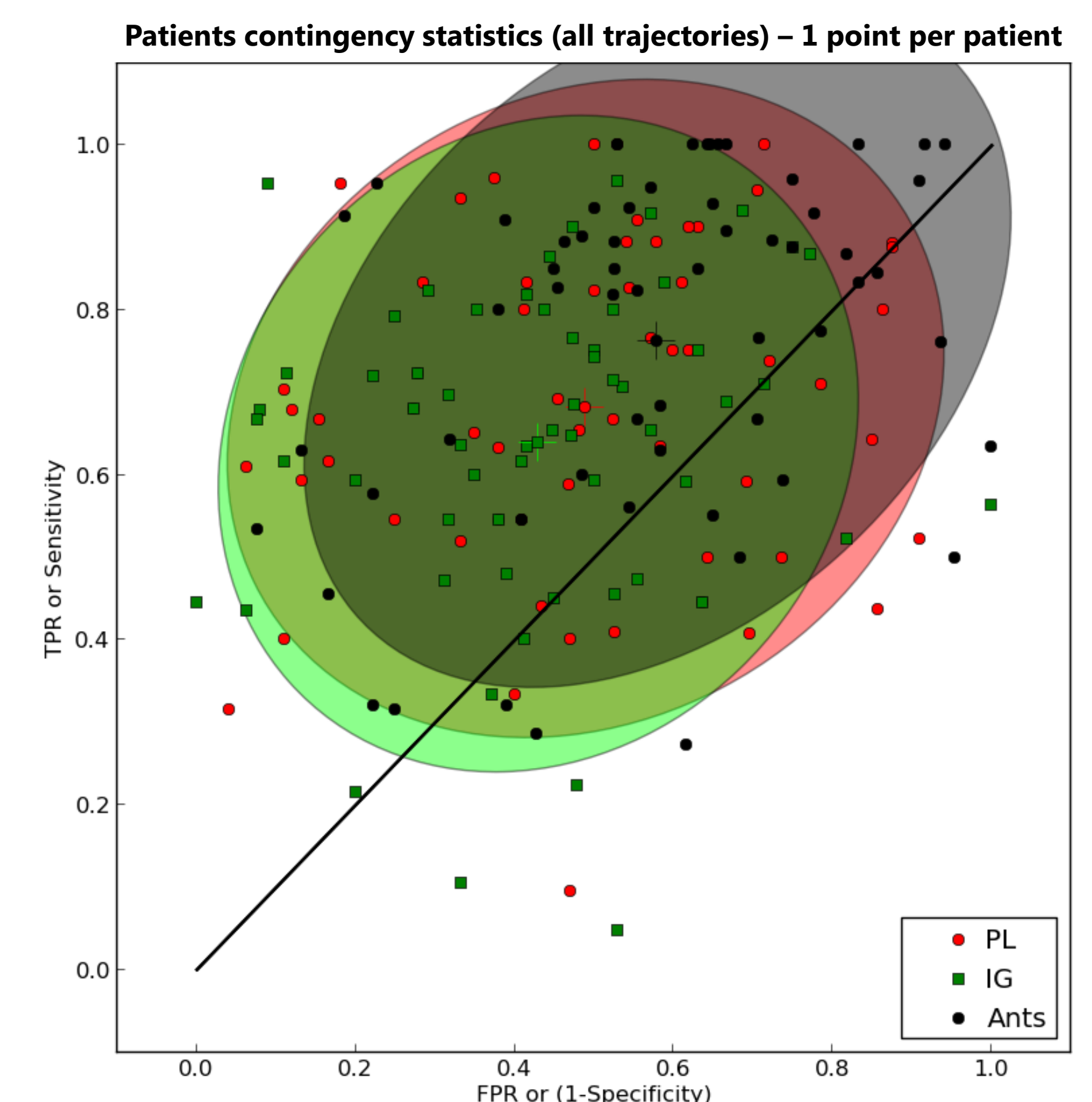
- **Mean intensity**, computed from the overlap between a patient's 1.5T T2w MRI (hypointensity) and warped STN mesh.



- **Retrospective cross-validation with microelectrode recording labels (MERL)** to assess the agreement between the predicted STN location (warped meshes) and per-operative electrophysiological annotations about the STN location. Confusion matrices were computed to evaluate sensitivity and specificity of each method.



- At each MERL location (electrode contact per explored trajectory), neuronal activity is recorded and labeled according to the electrophysiological signature (e.g. STN).
- The agreement between points labeled as the STN inside/outside warped meshes is evaluated.



CONCLUSIONS

Iconic-Geometric Registration Model:

- More precise atlas-to-patient registration, even for considerably different anatomies.
- Anatomically-robust deformations of the STN and other BG target nuclei that are invisible in 1.5T T1w MRI (globus pallidus, red nucleus, substantia nigra).
- Higher specificity (smaller rate of false positive STN regions) than competitive methods according to the retrospective analysis using electrophysiological data.

REFERENCES

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